NASA TT F-9363

NASA TT F-9363

INFLUENCE OF POROSITY ON THE MECHANICAL PROPERTIES OF METAL CERAMIC COPPER AND Cu-Al ALLOY

A. P. Savitskiy, Yu. I. Kozlov, V. I. Itin,
K. V. Savitskiy, and V. N. Zhdanova

Translation of "Vliyaniye poristosti na mekhanicheskiye svoystva metallokeramicheskoy medi i splava Cu-Al." Izvestiya Vysshikh Uchebnykh Zavedeniy - Fizika, No. 5, pp. 34-37, 1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON MAY 1965

INFLUENCE OF POROSITY ON THE MECHANICAL PROPERTIES OF METAL CERAMIC COPPER AND Cu-Al ALLOY /34

ABSTRACT

23686

The hardness and compressive strength of copper and Cu-Al alloy prepared by powder metallurgical methods are investigated as a function by their porosity. It is shown that the mechanical properties depend linearly on the porosity in materials with a low pore density.

Author

1. The effect of porosity on the mechanical attributes of metal ceramics and alloys has been investigated theoretically and experimentally in quite a large number of papers (refs. 1 to 10).

The implication of the equations given in references 1 and 2 is that cast materials are superior in their strength characteristics to metal ceramic materials of the same composition, unless the porosity of the latter is reduced to zero. This being the case, the porosity dependence of the mechanical properties would have to be a single-valued relation: the greater the porosity, the lower the quality.

It follows from reference 6, however, that the case can arise in which the mechanical properties will be enhanced with an increase in the pore content, within a definite interval. Such a dependence was in fact observed in reference 3, wherein pure platinum, prepared by sintering and hammering at various temperatures, was subjected to testing, and in reference 5, in which metal ceramic copper obtained by various methods was tested for hardness and compressive strength.

Numbers in the margin indicate pagination in the original foreign text.

The enhancement, observed in references 3 and 5, of the mechanical properties of a material containing a certain number of pores, relative to the cast material, may be attributed to two factors.

First, due to the peculiarities of the method of preparation, sintered materials generally have a far more fine-grained structure than cast materials (refs. 4 and 10). Consequently, with a small pore content, the influence of the structural factor can prevail over the diminution in mechanical properties caused by the presence of the pores themselves (ref. 11).

Second, very small pores with linear dimensions on the order of 10^{-6} cm must interact with dislocations, tending to hold them in check (ref. 8), and thus strengthening the material. So far, no one has obtained direct experimental evidence as to the existence of such a strengthening process. Nevertheless, if it is possible in principle, it should be expected in those situations when the material is not subjected to too high temperatures during preparation, which would tend to dissolve and coalesce the pores. In reference 3, which was published much earlier than reference 8, the authors arrived at the conclusion that the reason for the enhnaced strength of powder platinum may be highly disperse pores.

The anomalous nonmonotonic dependence of the hardness and compressive strength of metal ceramic copper on its porosity, as observed in particular in reference 5, may be the result of failure to regard the structure of the material. If one were to use a technology that would provide different porosities in the /35
specimens but approximately identical structure with respect to grain size, it could be anticipated that the porosity dependence of the mechanical characteristics would be more single-valued, even with a small content of pores.

Only meager experimental data have been published on the influence of a small porosity on mechanical characteristics, and it is impossible to draw any definite conclusions on their basis. With this in mind, the present paper is devoted to the investigation of the effect of a relatively low porosity on the hardness and compressive strength of sintered copper and Cu-Al alloy.

2. Metal ceramic copper specimens containing varying quantities of pores were prepared by repeated pressing and subsequent sintering (ref. 11). The advantage of this method over the usual procedure of varying the sintering time at high temperatures for the purpose of obtaining a fixed porosity is that the lower sintering temperature permits essentially any desired structure to be imparted to the material. By specifying the required compressive pressure, as well as the number of pressings, the pore content can be varied over a broad interval.

For copper, we used the following sintering temperatures: 250, 400, 500, 700, and 850°C. The Cu-Al alloy (10 at. %) was prepared by sintering at 500°C, followed by hot pressing at the same temperature. As the result of changing the specific pressure in the hot pressing, specimens with a porosity ranging from 0.3 to 15% were obtained. So as to equalize the structure of the material, all of the alloy specimens were annealed at 750°C prior to testing. As shown by investigations of X-ray patterns, all of the annealed alloy specimens, regardless of their porosity, had the same linewidth (331), within the limits of experimental error.

3. The porosity dependence of the hardness of metal ceramic copper sintered at different temperatures is shown in figure 1. It is apparent that this dependence is approximately linear and is in good agreement with the results of reference 2.

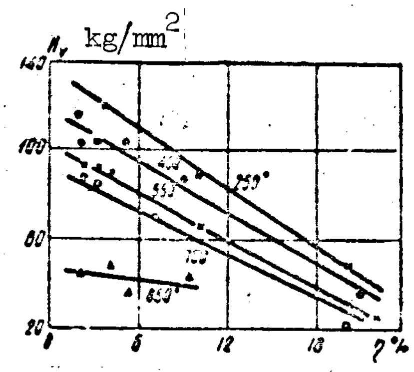

Figure 1. Dependence of the Vickers Hardness of
Metal Ceramic Copper on its Porosity.
The numbers give the sintering temperatures.

However, linear extrapolation to zero porosity gives hardness values corresponding to the hardness of cast material only for copper sintered at 850°C. In all other cases, as opposed to reference 2, extrapolation yields much higher values. The probable explanation for this is the particular mode of hardness (and compression) testing, which was not sensitive to the pores as stress concentrators. Nevertheless, as the figure shows, the hardness method is highly sensitive to changes in both the pore content and the structure of the material.

The slope of the lines depends on the sintering temperature: the lower the temperature, the greater the slope. The tendency seems to be for the lines to intersect in some porosity interval, in other words with a very high pore content, materials sintered at high rather than low temperatures out to have the /36
greater hardness. The dependence of the line slope on the sintering temperature is evidence that repeated pressing and sintering at the same temperature does not really make it possible to obtain perfectly identical structure in the material or, probably, the same porosity character. As already noted in reference 11, at low sintering temperatures repeated pressing leads to additional granulation of the crystals, as a result of which the number of visible

reflections in the Debye powder patterns decreases (fig. 2). The porosity dependence of the hardness of Cu-Al alloy also turns out to be linear.

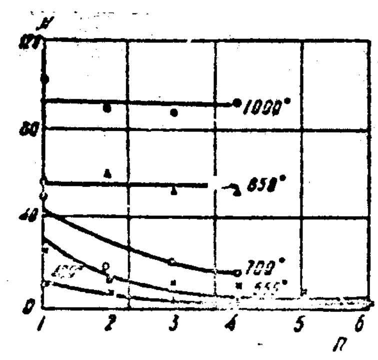

Figure 2. Dependence of the Number of Reflections in the Debye Powder Diagram Lines (331) and (420) on the Number of Repeated Pressings and Sinterings at Various Temperatures.

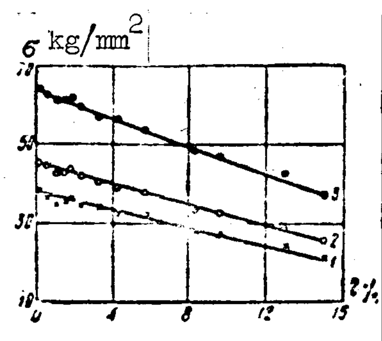

Figure 3. Dependence of the True Flow Stresses in Cu-Al Alloy (10 at. %) on the Porosity with 5, 10 and 30% Strains (curves 1, 2, 3, respectively).

The porosity dependence of the true flow stresses in Cu-Al alloy for different strains is shown in figure 3. As in the hardness tests, the mechanical properties depend linearly on the porosity over the entire investigated range of porosities. The compressive strength of the alloy containing 0.3-0.5% pores at 30% strain amounts to 64 kg/mm^2; the cast alloy, with the same strain, has a lower flow stress, amounting to no more than 50 kg/mm^2 (ref. 12).

The slope of the lines is slightly (yet enough to be perceptible) dependent on the strain. Evidently, this is caused by the fact that as the pore content is increased the actual strain diminishes. The gain in strength in this case will also be less, but this has to be manifested as a certain reduction in the flow stresses.

A similar, in other words linear, behavior is exhibited by the porosity dependence of the true flow stresses in the case of copper.

In summary, the results of the present study show that, although the mechanical properties of a material with a low pore content may surpass the corresponding properties of the cast material due to structural features, the dependence of these properties on the porosity remains linear, as before.

REFERENCES

1. Bal'shin, M. Yu. Dokl. Akad. Nauk SSSR, Vol. 67, No. 5, 1949.

2. Pines, B. Ya., Sirenko, A. F. and N. N. Sukhinin. Collection: Investigations on Heat-Resistant Alloys (Issledovaniya po zharoprochnym splavam), Vol. 3, p. 326. Izd. AN SSSR (Publishing House of the Academy of Sciences of the USSR), 1958.

3. Middleton, A. V., Pfeil, L. B. and E. C. Rhodes. J. Inst. Metals, Vol. 75, p. 595, 1949.

4. Hausner, H. H., Kalish, H. S. and R. P. Angier. J. Metals, Vol. 3, No. 8, 1951.

5. Savitskiy, K. V. Zhdanova, V. N., Savitskiy, A. P., Kulnikov, V. A. and T. I. Maslovskaya. Izvestiya Vuzov SSSR, Fizika, No. 6, p. 57, 1962.

6. Troshchenko, V. T. Poroshkovaya Metallurgiya, Vol. 3, No. 3, 1963.

7. Pines, B. Ya., Sirenko, A. F. and N. N. Sukhinin. Zh. Tekhn. Fiz., Vol. 27, No. 8, p. 1905, 1957. English translation: Soviet Physics - Technical Physics, Vol. 27.

8. Coulomb, P. and J. Friedel. Dislocations and Mechanical Properties of Crystals (International Conference, Lake Placid, N.Y., 1956), p. 366. Metallurgizdat (Metallurgy Publishing House), 1960. Original: Wiley, N. Y., 1957, p. 555.

9. Coble, R. L. and W. D. Kingery. J. Am. Ceram. Soc., Vol. 39, No. 11, p. 377, 1956.

10. Brophy, J. H., Hayden, H. W. and J. Wulff. Trans. AIME, Vol. 221, p. 1225, 1961.

11. Savitskiy, A. P., Zhdanova, V. N. and E. N. Girya. Poroshkovaya Metallurgiya (in press).

12. Bol'shanina, M. A., Makogon, M. B. and V. E. Panin. Collection: Investigations on Heat-Resistant Alloys, Vol. 3, p. 189. Izd. AN SSSR.

Siberian Physicotechnical Institute,
Tomsk State University

Received 23 February 1964

Translated for NASA by Stemar Engineering Inc.
4940 Long Beach Blvd., Long Beach, California